Nitrogen is "everywhere" and we cannot see why it's important

Research Project ● Sustai-N-able (SusN): Towards Sustainable Nitrogen Use Connecting Human Society and Nature

Interviewee: Kentaro Hayashi, Professor
Interviewer: Ken-ichi Abe, Professor

Nitrogen (N) is the fifth most abundant element in the solar system, and nearly 80% of the air is molecular nitrogen (dinitrogen, N_2). Life on the Earth cannot live without N as an essential component to form proteins and DNA. Whilst N offers great benefits to humanity as fertilizer for food production, raw materials for industrial production and fuel, it always lays behind every environmental issue. Our N use unintendedly causes N pollution, which has been gradually undermining the health of people and nature. "We cannot talk about the future of our planet without looking at N. Unless we look at the whole picture of the complex N cycle, we will be never able to solve environmental issues," says Prof. Hayashi. His project's abbreviation, "Sustai-N-able," with "nitrogen (N)" at the center, does highlight his determination.


Kentaro Hayashi

Abe●Your project has finally begun on full scale as PR (Pre-Research) in FY2022. I can look up your project's overview in the Research Institute for Humanity and Nature (RIHN) Prospectus, and I have had some opportunities to learn about the same as it has progressed from IS (Incubation Study) phase to FS (Feasibility Study), then to PR, but to be honest, I still haven't got the gist of it. Although I understand that the project focuses on the N issue, it's just difficult for me to understand what your project is trying to archive.

First of all, the fact that N is one of the major environmental issues is not well understood even by those of us who are conducting research at RIHN.

Hayashi●Absolutely. It has been a constant question since the IS and FS phases. They always told me, "I don't know why N is an issue" (laughs).

You also often asked me, and you would say, "I think I understood," when I explained, but then you would repeat, "I think I am confused again" (laughs).

Abe●Perhaps it's because the N issue is so complex, but I just felt like I was stuck in a fathomless swamp.

Hayashi●I recently had some opportunities to visit the Ministry of Agriculture, Forestry and Fisheries (MAFF), the Ministry of the Environment, the Ministry of Economy, Trade and Industry, and the Ministry of Land, Infrastructure, Transport and Tourism to talk about the N issue, and they all responded in the same way. In a sense, I think it's only fair, and today I would like to explain why that is so.

Abe●I can finally get out of the swamp (laughs).

How much do we know about "N that is everywhere"?

Hayashi●Nitrogen is very important and essential but people just don't get that.

For example, living organisms need N to make proteins and DNA. We, humans, can only take in N by "eating" it. For us to produce food to eat, we also need N as fertilizer. Plants also need N to grow and to produce enzymes necessary for photosynthesis.

Abe●I see. Then, it's basically the same as when we at RIHN do very conscious efforts to tell the general public how important biodiversity is, but it's difficult for them to understand. RIHN's first Director-General, Prof. Toshitaka Hidaka always said, "so that high school students can understand," but it's quite difficult to convey something so obvious. Nitrogen is "critically important" in this sense.

Hayashi●That's exactly correct. It's like breathing every day. The air we breathe in contains 78% nitrogen.

Useless N and usable N

Abe●Nitrogen is present everywhere in our lives, plus a significant portion of our body is composed of protein containing N. And yet, we don't really know what the N issue is.

Hayashi●Actually, there are two types of N. One is the most abundant N species in the air around us, which basically "does nothing" in both good and bad ways. This inert N species is called "nitrogen gas (N_2)." Although I just said it would not do anything or useless, if the air were composed only of N_2 (chisso), we would asphyxiate (chissoku) and die. This is how the Japanese name of N, or chisso comes from chissoku.

Abe●Chisso (N) comes from chissoku (asphyxiation), I see.

Hayashi●In German, it's "stickstoff," meaning asphyxiating substance, which was then translated directly into Japanese. Humanity hadn't known the existence of this "useless N that does nothing" and only discovered this element in the late 18th century.

Abe●That's why it's so hard for people to understand when you tell them it's an issue (laughs).

Hayashi●Exactly. It's around us everywhere, and it really doesn't do anything. Even when we breathe it in, it just goes in and out of our bodies and it doesn't build muscle or grow any other organs. So, we as animals have to eat "usable forms of N." Animals take in N compounds such as protein and amino acids, and plants take in forms of ammonium and nitrate.

Abe●Do we call these "usable forms of N" active N as opposed to inert N?

Hayashi●It's called "reactive nitrogen (Nr)." There are various forms of N, but all N compounds other than N_2 is called Nr.

In fact, there is a small amount of Nr in the air as well. Let's say, if we collect only N_2 from a balloon with a diameter of 1 m, the diameter of N_2 would be 92 cm. If we collect only Nr, the diameter would only be about 0.7 cm. Living organisms want this small amount of Nr. And this tiny existence of Nr controls the material cycling in ecosystems.

Abe●The word "cycling" reminds me of the

This interview was conducted in June 2022. The statements made by both parties are based on the findings at the time of the interview and the situations in Japan and overseas. As one year has passed since the full-scale launch of the project at the time of this publication in August 2023, the project activities have become more concrete and some events may differ from the views expressed at the time of the interview, they have been included to respect the documentary nature of the interview.

For the most up-to-date information on this project activities, please visit their website.

radar chart of the Planetary Boundaries (Fig. 1), and the "N cycling" out of the nine subsystems far transgresses its boundary.

Hayashi•The thing is, this radar chart shows only one aspect of N. It's shown as an indicator to prevent eutrophication in shallow coastal areas. It's calculated using numerical models on a global scale and shows the acceptable level of the anthropogenic N loading and then, sends an alert to humanity because the actual load is much higher than that, telling all of us, "this is dangerous."

Abe•That means it's not referring to the whole N cycling, then.

Reactive N (Nr) lurking behind environmental issues

Hayashi•There are various forms of Nr, the most known of which is nitrous oxide (N_2O) as a greenhouse gas.

Actually, N_2O has a greenhouse effect about 300 times greater than carbon dioxide (CO_2) of the same weight. Although the atmospheric levels of CO_2 are much higher, N_2O is also an important greenhouse gas, and destroys ozone in the stratosphere.

Abe•Not only chlorofluorocarbons (CFCs) do that...

Hayashi•While there has been considerable progress in eliminating CFCs, N_2O emissions continue to increase. It is recognized that N_2O is now the largest contributor of the stratospheric ozone depletion.

Abe•People really don't know that.

Hayashi•It's already common knowledge among experts, so we don't have to venture to mention it. According to the radar chart of the Planetary Boundaries, the stratospheric ozone depletion is settling down compared to the other eight problems and has subsided within the safe range. In terms of N_2O, I feel it's better to give priority to the climate change issue.

Abe•Is there anything else related to N that we should particularly take notice of?

Hayashi•I mentioned earlier that there is only a tiny amount of Nr in the air, but this "tiny" is the key here. For example, it's associated with aerosols, particularly fine particulate matter called PM2.5 defined as particles of less than 2.5 ㎛ in diameter. PM2.5 is so small that you can inhale it and it can go deep into

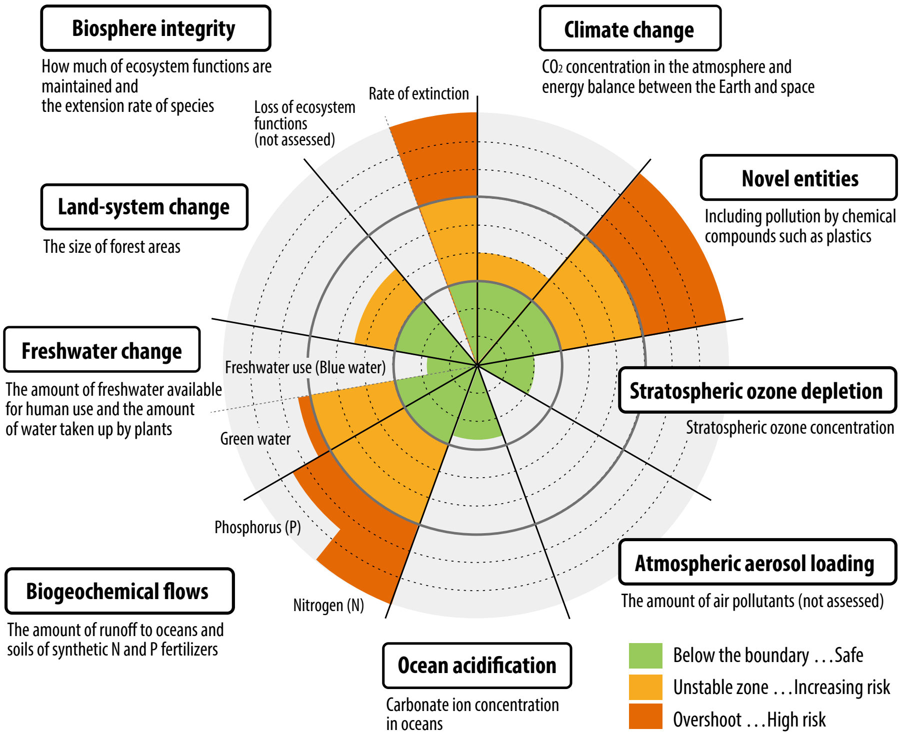

Figure 1: The Planetary Boundaries' update status

The Planetary Boundaries concept proposes a set of nine planetary boundaries that humanity must not exceed to survive sustainably on the Earth and illustrates its update status in the radar chart format. In Japanese, it's called "Chikyu no genkai (limits of the Earth)." A team led by Dr. Johan Rockström, an environmental scientist from Sweden, first announced this concept in 2009, and it has been updated several times. This chart is based on data published in 2015.

Source: Azote for Stockholm Resilience Centre, based on analysis in Wang-Erlandsson et al 2022

your respiratory system, causing respiratory diseases. Nitrogen is a significant component of these particles. Specifically, fine particles of nitrate and ammonium account for a large percentage of the chemical composition of PM2.5, as some papers even indicate that it composes as much as 40%. Therefore, N is also associated with the "atmospheric aerosol loading" in the Planetary Boundaries. In the very beginning, I mentioned that "the N issue is difficult to understand," but if you look beneath various environmental issues, you will find that N is lurking behind almost every issue. But since we can't see it on the surface, it becomes difficult to understand its impact. We eat to survive, and we don't even think twice to use N as fertilizer for food production. However, it's not well known that N is behind many environmental issues.

Microorganisms driving the natural N cycling

Abe•Though N is not visible to our eyes, it is associated with pretty much everything. Now we understand that, but what about "cycling"? For example, what about the cycling between Nr and N_2?

Hayashi•Microbes were originally driving the N cycling. Some microbes can convert N_2 into ammonia (NH_3), and this process is called "biological N fixation."

Abe•I have heard, for example, root-nodule bacteria of legumes have such ability...

Hayashi•Some live symbiotically with legumes while others are free-living microbes. Blue-green algae or cyanobacteria are probably the best known. Many microbes have this ability. They are scattered over a wide area, and each slowly and independently produce NH_3 from

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N_2, which is then converted into amino acids for plants to use. This is the start of the N cycling in ecosystems.

On the other hand, there is a process called "denitrification," in which nitrite and nitrate in ecosystems are reduced to N_2. This is also an important microbial function.

Abe●Do these microbes perform both functions?

Hayashi●They are carried out by different microbes. The cycling works out as they both are present in ecosystems. Otherwise, if only fixation process is done, Nr will continue to accumulate. If only denitrification is done, nutrients will be lost. Since there are microbes that fix N into Nr and other microbes that reduce Nr into N_2, the N cycling is balanced. And, plants and animals exist in between, and they utilize the nutrients successfully.

For example, N-fixing microbes initially use the fixed N to build their bodies, in other words, organic compound. When they die, they are decomposed into ammonium, which are quickly absorbed by plants to grow their bodies. If there are animals present, they eat plants and grow, and animals also have the predator-prey relationship. When plants and animals die, microbes decompose their bodies and circulate again. In the final stage of such N cycling, some microbes turn Nr into N_2 and return it to the atmosphere, and they are called "denitrifying microbes."

Ken-ichi Abe

Abe●I don't think I've heard much about them.

Hayashi● I think our field is the only one that uses these terms (laughs).

Abe●However, they play a very important role.

Hayashi●Yes, exactly. The term "decomposer" is often used, but the role of decomposers in ecosystems is often discussed in the context of the carbon (C) cycling of returning organic matter into CO_2.

Abe●We learn about the C cycling as the mechanism of photosynthesis, don't we?

Hayashi●Carbon and N are actually associated with each other. This is because organic matter is composed of C, N, hydrogen, oxygen, phosphorus (P) and some other elements, so C alone cannot circulate on its own.

Abe●So, N plays an important role behind the C cycling.

Hayashi●It's not actually "behind," but it rather controls the whole process. It looks like C is doing the work, but it's N and P that are essentially controlling the C cycling.

There is a book entitled "Eat Like the Animals" written by a nutritional ecologist and an entomologist at the University of Sydney. A Japanese translation of the book is available with the title "Kagakusha-tachi ga kataru shokuyoku (Scientists Talk about Appetite)." They says that all living things eat because these things want protein. That was true when they first researched insects. Then they looked at larger animals, and it was all the same. Finally, it was also found the same when they looked at human beings. In sum, the fact that we all eat to have protein means that we want N.

Abe●Our staple food today is carbohydrates, but some people believe that our health problems began when we started eating carbohydrates. Prof. Taro Yamauchi of RIHN Sanitation Project (*1) also said, "the problem is that rice is too tasty"(laughs).

Hayashi●That would be true (laughs). I read in a book by Shinya Nishimaru, a food ecologist that we should never bring Japanese rice to Papua New Guinea when doing field research. He said that people who had been eating taro and yam would be in so much trouble if they experienced and learned the taste of rice (laughs).

Abe●As far as I remember, his research field was also Papua New Guinea and the Solomon Islands.

Hayashi●Rice also contains about 6% protein. When Japanese people had rice as the main part of their diet in the past, they would eat about 3 or 4 go's (about 330 g per go) of cooked rice at a time. Rice was also a source of protein.

Abe●It is different now, isn't it? Does wheat contain less protein than rice?

*1 The RIHN Research Project "the Sanitation Value Chain: Designing Sanitation Systems as Eco-Community-Value System" which was completed in FY2021.

↑ Download from here.

This brochure was developed as part of the project's activities to provide an overview of the N issue to various stakeholders and to inspire free discussion. Both Japanese and English versions area available for download on the project website.

Hayashi●It does contain a certain amount such as gluten.

Abe●An old classmate of mine who joined the MAFF was searching for effective genes to bring the protein level of wheat up to that of rice. He patiently studied about 4,000 varieties of wheat and finally found it after the 3,000 varieties. I was amazed with his patience (laughs).

Hayashi●Thremmatologists always have to take that way (laughs).

The Haber-Bosch process that changed the balance of natural N cycling

Abe●We are getting sidetracked, so let us get back to "cycling." The problem is that the N cycling is now greatly distorted, isn't it?

Hayashi●As I mentioned earlier, the balance in natural ecosystems used to be maintained by some microbes that fixed N_2 into Nr, while denitrifying microbes turned it back to N_2. Then, once humanity came into the picture, they gradually created the "anthroposphere" within the "biosphere."

Alchemy of "making bread from air"

Hayashi●It's obvious that as the population grows, the demand for food increases. Food harvested from the natural world could no longer feed the increasing population. There

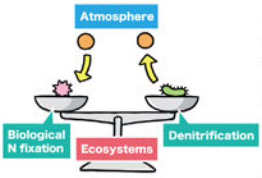
What is "Nitrogen?"

Nitrogen is the fifth most abundant element in the solar system with the symbol "N."

Earth's atmosphere is composed of 78 % molecular nitrogen (dinitrogen: N_2).

Nitrogen is crucially important to living things as an essential component to form proteins and DNAs. Nitrogen makes up about 3% of the human body weight.

However, N_2 abundant in the atmosphere is inert and does no harm nor good. What is needed is reactive nitrogen (Nr), a form usable to living organisms. Nr has diverse chemical species.



Some microbes produce Nr from N_2 in ecosystems. Plants absorb Nr to grow. Herbivores eat plants and carnivores eat herbivores to deliver Nr into their bodies. Microbes also decompose Nr in organic matter and eventually convert it back to N_2.

Humanity has also been living by circulating Nr. In the past, agriculture fully depended on Nr in various organic matter such as manure and waste.

Shortage of Reactive Nitrogen (Nr)

The world population has increased gradually. More food was required for us to survive. How were we able to yield more food? The answer lay in "fertilizers." We needed Nr as fertilizers for crops.

In the early 20th century, the Haber-Bosch process was developed to artificially synthesize ammonia (a species of Nr) from N_2. This method allows us to produce chemical fertilizers as desired.

Nr has various uses other than fertilizers, e.g., industrial materials such as polymers and explosives, and an alternative energy source as fuel ammonia.

What is the outcome of artificially synthesizing Nr?

are several strategies to overcome this problem, one of which is to increase the area of farmland. But there is a limit, of course. Then, the next possible option is to use fertilizer to increase the production per area, i.e., yield.

Historically, livestock waste and, of course, human waste were used as fertilizer. However, as a matter of course, this was done by simply returning what people and livestock had eaten to land, so if there was not enough food to eat, the availability of such the organic fertilizer also decreased. This means that we need other forms of fertilizer. That is why humans have been searching for materials for fertilizer for a very long time.

Then, what happened was the discovery of guano and Chilean nitrate. Guano is the accumulated excrement and carcasses of seabirds on the islands off the coast of Peru. Chilean nitrate can be found in the Atacama Desert, which straddles Peru, Bolivia, and Chile. The area used to be an ocean, but it has dried up due to uplift. Nutrient salts that had accumulated in the ocean spread out with low-grade contents. People rake this layer to collect nitrate salts.

But these fossil N will be eventually gone if they keep digging up. Guano has been already gone. Chilean nitrate is still available, but not efficient because of its low-grade content in the desert soils.

Just before the turn of the 20th century, Sir William Crookes (*2) said during his speech at the British Association for the Advancement of Science, that if things continue as they are, humanity will starve in the near future, and the only way to avoid this is to artificially produce N fertilizer. By that time, it was known that abundant N_2 existed in the atmosphere, so the competition in technological development for artificial N fixation began.

Abe●It is like alchemy, isn't it?

Hayashi●Alchemy, yes exactly. As you all know, it's "the Haber-Bosch process."

Abe●So, the "unusable N" in the atmosphere can be....... something like that can be done.

Hayashi●When Fritz Haber was working on this research, people made fun of him, saying it was a "technology for making bread from air." Precisely speaking, it's "making fertilizer from air, growing wheat with the fertilizer, and making bread with the wheat," but he was called "a strange person who is trying to make bread from air," skipping over the in-between steps.

However, he succeeded in synthesizing NH_3 from N_2 and hydrogen on a bench scale. And Carl Bosch, who was an engineer at a large German chemical company called BASF, which still exists today, bought out Harber's research achievement. He, then, took the laboratory recipe and brought it to a level where it could be industrially produced. That was in the early 20th century.

Abe●This is truly a revolutionary innovation.

Hayashi●Absolutely, and there is plenty of N_2 around us, which is the ingredient for this process. All we need now is hydrogen. There are various techniques for this, such as electrolysis of water or extracting only

hydrogen from coal and natural gas. Then, we can produce fertilizer.

Abe●An energy source is obviously necessary, right?

Hayashi●Right. Back in those days, the energy source was mostly fossil fuel combustion. You would have to go to an island in South America to harvest guano, but the NH_3 production using the Haber-Bosch process made it possible to produce fertilizer anywhere in the world as long as hydrogen and N_2 were available together with an input of energy.

Fertilizer in peacetime, gunpowder in wartime

Hayashi●I'm sidetracking again, but there is a reason why the Haber-Bosch process was developed in Germany. Germany at that time was already in a state of quasi-war, or rather, a state close to conflict with Britain, and Germany needed fertilizer to feed its own people. In addition, the negative side of N is that N can also be used as gunpowder.

Abe●Oh well, whether you think of it as negative or positive is.......

Hayashi●I feel that they rather prioritized that aspect. Potassium nitrate as an Nr species can be used as explosives. Nitroglycerin is too unstable to use as it is, so it was soaked in diatomaceous earth and fused to make it stable enough to use. Since it was Nobel who invented

*2 Sir William Crookes (17 June 1832 - 4 April 1919) was a British chemist and physicist. He is known for his discovery of the element thallium and works on cathode rays and became president of the Royal Society in 1913.

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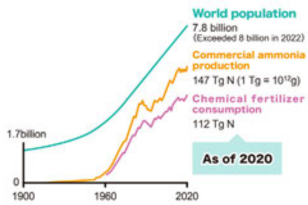
Human Nr Production Changed the World

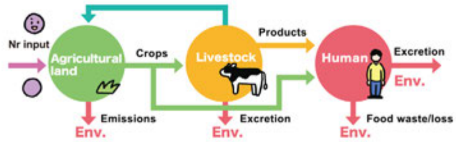
How much Nr has humanity used? Commercial production of ammonia by the Haber-Bosch process began in 1913. Since the 1960s, ammonia production and chemical fertilizer consumption have grown rapidly and continue to this day. Nitrogen fertilizers have improved food production and thereby supported the growing world population.



Nitrogen fertilizers have also increased crop yields, part of which is used for animal feed, increasing livestock production.

However, much of the Nr input for food production leaks into the environment. The world's nitrogen use efficiency, the ratio of N in harvested crops to the total input N, is approximately 50% for crops and only 5%–20% for livestock products. The rest is lost to the environment unless we circulate it properly.

If you take in the same amount of protein, livestock products tend to result in a higher Nr loss to the environment than crops. Food loss and waste not only waste the food that is thrown away but also the Nr input to produce the food.



Nr leaks into the atmosphere, soil, water, and oceans. Once lost in the environment, Nr travels around, changing its forms, and exhibits different impacts depending on species.

Agriculture is not the only source of Nr loss. The combustion of fossil fuels to generate energy for more comfortable life living and waste incineration also emit Nr, typically nitrogen oxides, to the atmosphere.

Nr in exhaust gas and wastewater can be converted back to an unharmful form, N_2 through treatment, but it is expensive. It is, therefore, important to use Nr more efficiently.

What problems can the Nr loss to the environment cause?

this dynamite, we can see that the Nobel Prize also has a deep connection with N.

Because of the British blockade of the sea, Germany could no longer import Chilean nitrate, leaving them with no means to produce fertilizer and gunpowder. They had to do something to produce on their own, so they stepped up efforts toward developing N-fixing technology.

Abe•That's why it started in Germany.

Hayashi• I don't think that was necessarily the only reason, but many competing researchers were also from Germany. Wilhelm Ostwald, who invented a process for manufacturing nitric acid, and Walter Nernst, who worked on thermodynamics, all received Nobel Prizes in chemistry. Germany in those days was terrific.

Nr leaking out of the anthroposphere

Abe•The Haber-Bosch process is a revolutionary technology with its almost unlimited materials.

Hayashi•You can produce as much as you want, and the more fertilizers you put on farmland, the more yields you can get. But then, the production of fertilizers alone would not be enough, so we need to develop new varieties that can yield more responding to the increased fertilizer application rate, invent agrochemicals such as pesticides and herbicides, and mechanize farm equipment….

The Green Revolution was the result of developing all these things. It's around 1950s and 60s after the World War II, when the consumption of N via the Haber-Bosch process began to increase rapidly, and it continues to do so today.

Abe•The problem is that it continues to increase.

Hayashi•When we produce a large amount of synthetic fertilizer and we keep its cycling within the anthroposphere, there is not much of a problem. Unfortunately, however, a significant portion is leaking out. There are various estimates, but roughly speaking, 80% of input N does leak out.

Abe•You mean, for example, into farmland?

Hayashi•Not only for agricultural use, but when we burn fossil fuels for energy conversion, it would produce nitrogen oxides and other substances being emitted to the atmosphere. Of course, we have the technology for wastewater and exhaust gas treatment, which allows us to convert a significant portion of Nr back to harmless N_2. But that involves a cost. And energy and materials are needed for such treatment. The remaining Nr is lost to the environment and causes issues such as global warming, eutrophication, and air pollution.

Abe•So today, the amount of Nr that cannot be processed by the microbes on the earth.......

Hayashi•Not converted back to N_2 and leaks out.

Abe•Then, it's causing all kinds of problems.

In the Planetary Boundaries, thresholds are set for the biochemical flows of P as well as N. Phosphorus production still depends on mineral phosphate because there is no manmade alchemy like the Haber-Bosch process.

Hayashi•The only means we currently have is to collect it from where densely concentrated.

Abe•For P, the solution is quite easy to understand. However, in the case of N, there are various forms of N, and it's also quantitatively massive.

How can we find a solution to this issue, which is never easy?

Now let's talk about your project.

How to deal with the N issue closely related to our diet

Hayashi•80% of our N use is for fertilizer. That is why food production is so important here. But this is two sides of the same coin. Japan imports a large portion of its food and feed, so more than half of N use in Japan is actually for industrial purposes.

Abe•For industrial purposes?

Hayashi•An easy example is production of chemical fibers and plastics such as nylon and urethane. We do use quite a lot of N for such industrial production. However, on a global scale, 80% of the N created by the Haber-Bosch process is used for agricultural purposes.

Abe•So, if we could do something about this 80% of N use for agricultural purposes, would you say that the N cycling would improve considerably?

Hayashi•Yes. The Haber-Bosch process, which was invented 110 years ago, is an entry point of the current N cycling. A significant portion of the N used for food production leaks to the environment, so if we can improve its N use efficiency (NUE, here the ratio of harvested N to the total N input), we can definitely improve the N cycling.

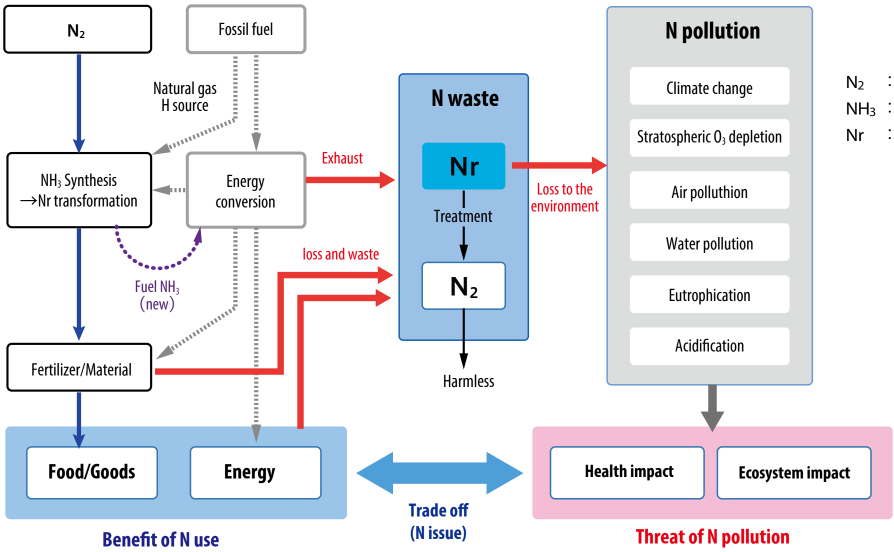
Looking at our diet through the lens of the NUE

Abe•Industry is a closed system while agriculture is an open system. When you say improving their NUE, do you mean preventing N loss to the environment?

Hayashi•In short, yes. However, it's not necessarily only about improving the NUE of agriculture, but it also involves "what we eat."

Abe•So, you mean we have to think not only about agriculture but also our diet?

Hayashi•Yes. The crop production NUE in the world is roughly 50%, but with livestock production, its NUE downs to 5% to 20%



N_2 : Dinitrogen
NH_3 : Ammonia
Nr : Reactive Nitorogen (Compounds other than N_2)

Fig. 2: Tradeoff between the benefits of nitrogen (N) use and the threats due N pollution (N issue)

The Haber-Bosch process, the invention of the artificial synthesis technology for ammonia, made it possible to produce as much reactive (Nr) as desired, and Nr provides great benefits to humanity as fertilizer for food production and materials for industrial production. On the other hand, most of the Nr used by humans is lost as the reactive Nr to the environment. Nitrogen use efficiency is low in the food production process, but food loss is another major factor. The Nr emission causes various types of nitrogen pollution, and damages to ecosystem health. The tradeoff between the benefits of N use and the threats due to N pollution is called the "N issue."

depending on farming styles and species. Livestock nowadays are sometimes fattened on grain that humans can eat, so it's no surprise that the livestock production NUE would naturally drop. Livestock are animals, and obviously not everything they are fed turns into meat. They repeat eating and excreting to grow bigger and produce meat or eggs, so the NUE is inevitably lower.

Therefore, the NUE varies greatly depending on, for example, whether you eat plant-based protein such as soybeans or meat to have the same amount of protein.

Abe●Tofu is better than meat.

Hayashi●I mean it's better than meat, but soybeans also have its own problems if we look closely... It also involves the aspect of food culture and the freedom to choose what to eat. But at the very least, I would like everyone to imagine how eating something will affect the environment.

When eating meat, beef or pork, for example, you should better know how cows and pigs live and walk. We should think about where and how the food we are going to eat came from. We tend to look at food traceability often from the perspective of consumer safety and security, but it's also related to environmental issues. If we better understand how "eating" is associated with the environment, we will be more conscious of the food we eat, which will hopefully lead to reducing food loss.

Thinking about environmental issues through food

Abe● I understand that two of your project members are from Tsuji Culinary Institute.

Hayashi●Our project wants chefs, in other words, people who work with food, to have correct knowledge of the environment. Green jobs refer to jobs that contribute to environmental conservation and sustainability while fulfilling the requirements for "decent job." I believe that our project can contribute to making more opportunities for them to create new green jobs. Rather than blindly thinking that this might be a good way, I expect that they will be well equipped with basic knowledge of environmental issues, have good understanding of "this will have this kind of effect," and expand the horizons of new ideas.

Recently, I've been having more and more opportunities to talk about N at high schools, and the students have been very receptive, writing in their post survey forms that "it was interesting to learn." I think, if I continue to do this process one step at a time, more and more people can learn about the N issue. I especially would like junior high and high school students to learn about this.

Abe●RIHN and the Kyoto Prefectural Board of Education have signed a Memorandum of Understanding (*3) to collaboratively develop environmental education and research methods. I teach environmental education classes at Kyoto Prefectural Rakuhoku High School, a Super-Science-Highschool located near RIHN.

We also have an agreement on academic exchange with Miyazaki Prefecture. Miyazaki Omiya High School, one of the leading schools in Miyazaki Prefecture, has been selected for the Super Global High School (*4) and World Wide Learning (*5) projects promoted by the Ministry of Education, Culture, Sports, Science and Technology, and they are developing new recipes that make the most of local food products, and distributing to the world.

Hayashi●That sounds very compatible with our project. I would love to speak at the high school about how food is deeply connected to the environment.

Abe●Food is more than just being "tasty."

Hayashi●Another food-related idea our project is working on is to create opportunities for people to feel the connection between food items and nature through the lens of food. Japanese diet could have both traditional Japanese food and the neo-Japanesque food that will be newly created in the future, but Japanese diet makes it possible for us to properly enjoy change of seasons and connection with living things.

In Japan, we have "shun (top season)" for many food items. Not only we can savor seasonal food, thinking "they are tasty because

*3 Signed in June 2022. This MOU aims at promoting the collaborative implementation of environmental education, and research development in Kyoto by RIHN researchers giving on-site classes at schools, giving trainings to teachers, and helping create teaching materials, while RIHN will utilize firsthand feedback from the field of education in its research activities and the creation of educational programs, etc.

*4 The program aims to nurture future global leaders who can play an international and active role and promotes the collaboration with both Japanese and international universities, companies and international organizations to engage in cross-sectional, comprehensive, and exploratory learning on global social issues and business issues.

*5 The Support Project for Building the World Wide Learning Consortium. With the aim of developing innovative global human resources, the consortium will collaborate with universities, companies and international organizations in Japan and abroad to research, develop, and implement advanced curricula.

Nitrogen is "everywhere" and we cannot see why it's important

they are in season," we can also appreciate each season, thinking "the season is passing by" while eating them. It's just like saying, "see you again next year."

Food is not just nutrition, but through eating, we can understand that food items are also living things, and that these living things are connected to nature and to a vivid sense of the season. Our project hopes to increase opportunities for people to understand by seeing with their eyes, smelling with their noses, and tasting with their palates, not just by words.

Knowing and sharing the current situation in Japan and discussing "the futurability" together

Abe●In Japan, the major use of N is for industrial purposes, but does this mean that the mode of N cycling differs completely from region to region?

Hayashi●Yes, there are tremendous differences.

Abe●How does your project consider such regional variations? I think some regions thoroughly use fertilizers in agriculture, and I would like to know about such regional differences. ...... When you first told us about the concept of your project, you talked about "the N cycling on a global scale," I think…

Outsourcing the responsibility of N pollution to other countries

Hayashi●I would like to separate the framework of this project and the N issue in general.

First, this project will focus on Japan. There are reasons for this: Japan imports not only various products but also a significant amount of fossil fuels, which contain a lot of N in total, all of which would be released to the atmosphere when combusted. I explain in one of my papers that significantly more N comes from fossil fuels than fertilizers in the case of Japan.

Of course, we also import a huge amount of food and feed. This means that we are making the countries of production responsible for N pollution during production. N pollution is occurring at the production sites, but we are only paying for the final products. In the future, when we import products, we may need to compensate the cost of countermeasures for such environmental impacts. Japan would not like to see that happen.

However, I would say that Japan is just too unaware of this fact. Looking at the state quo of consumption in Japan, I believe that we are somewhat on the way out of mass production and mass consumption, but the way we handle food is recklessly inefficient.

The annual amount of Japan's food loss is 7 million tons. Japan's rice production is 8 million tons, so it's about the same. The UN World Food Program (WFP) provides about 4 million tons of food aid, so Japan, just one country, is throwing away nearly twice that amount. I believe that we had better first learn about this. While our project is researching on the N cycling, we are also trying to raise awareness about food through N.

Ecosystem restoration, a hard task

Hayashi●On the other hand, if we look outside of Japan, there are areas in trouble without sufficient N in the soil. Sub-Saharan Africa (the region south of the Sahara Desert) is a typical example. They are economically distressed, so they cannot afford fertilizer. But the population is so large that they have to find a way to somehow feed people, so they are simply forced to continue farming, no matter what.

What happens when they continue like this is that the organic matter stored in the soil decreases gradually, and the land becomes less and less fertile. Once the soil becomes too depleted, no matter how much fertilizer and water are applied, it cannot hold and absorb them and they would runoff.

Abe●This is exactly what Prof. Shuichi Oyama of the Organic Material Circulation Project (*6) is doing in the Sub-Sahara, putting organic waste collected in urban areas into farmland for greening. This is still at the beginning stage. ......

What about Japan? For example, the Seto Inland Sea in Japan is currently, in fact, facing oligotrophication.

*6 The RIHN Research Project that started in FY2022 as Pre-Research: "Building up organic material circulation system among urban and rural area: Toward the integration of local perception and scientific knowledge."

When the Seto Inland Sea experienced eutrophication in the past, I thought Japan was quite competent since the government controlled the total inflow of N and P. I come from a fisherman family, and they were talking about how the catch was decreasing during that time.

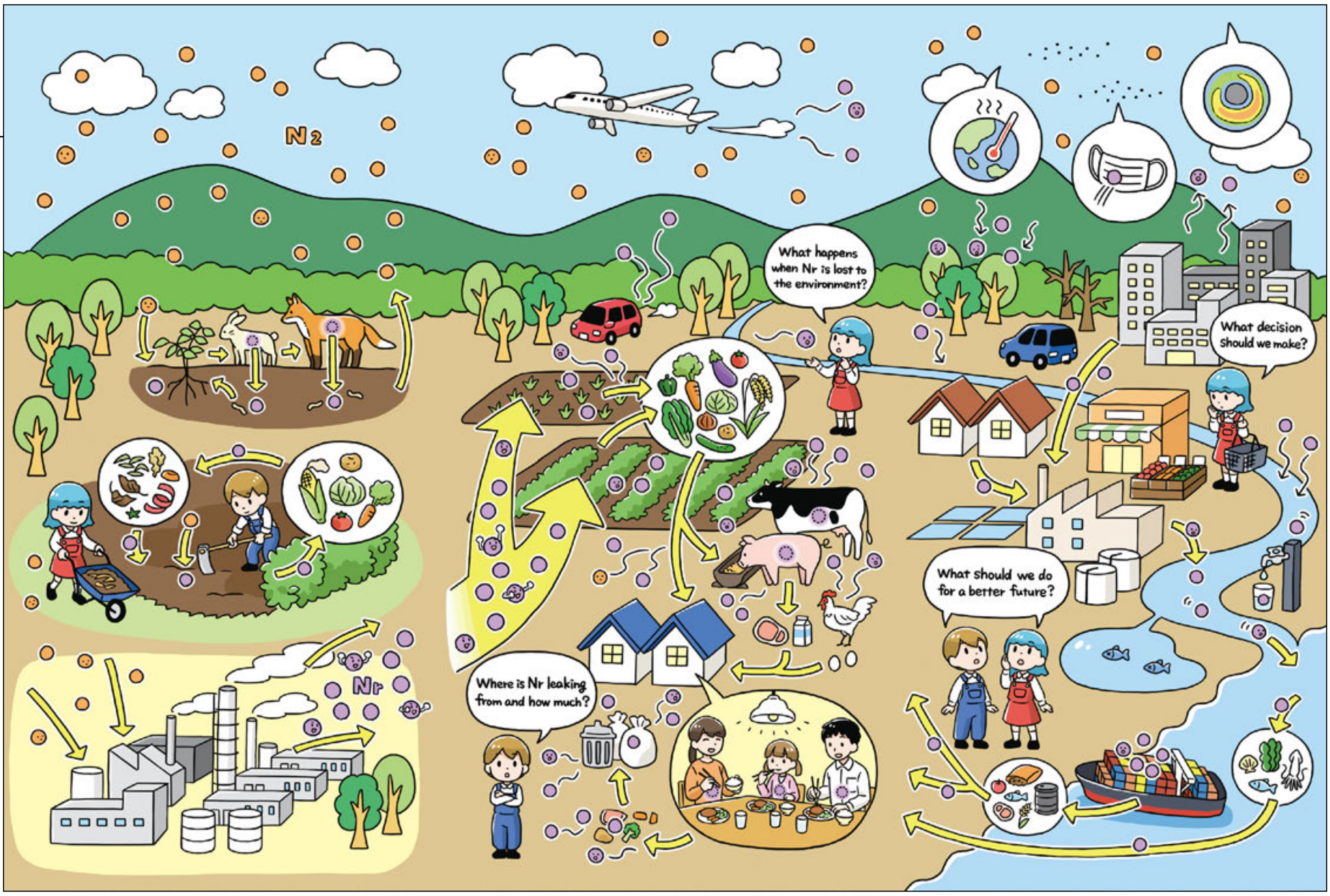
Professor Emeritus Tamiji Yamamoto at Hiroshima University, for example, is one of those with the idea of "using the Seto Inland Sea as garden or field." He also argues that what the Seto Inland Sea needs now may be N and P.

Hayashi●That's quite possible.

Abe●Even within Japan, the nutritional status varies from region to region and from site to site.

Hayashi●Absolutely correct. I think there are regional variations. We know of the oligotrophication of the Seto Inland Sea, but that is also the case in some parts of Lake Biwa and Lake Suwa.

To be honest, I don't think the expression "oligotrophication" is necessarily correct. I think, if we look at what is exactly happening



While N provides great benefits to humanity as fertilizer for food production, materials for industrial production, fuel among others, it also causes N pollution to the environment and poses a wide range of threats such as climate change, stratospheric ozone depletion, air pollution, water pollution, eutrophication, and acidification. The brochure introduces the status of the N cycle with easy-to-understand illustrations.

there, a different term would be more suitable to describe the situation.

A red tide or blue tide occurs in the process of eutrophication, resulting in large-scale death of living things. This could result in the loss of key species and/or a decrease in biomass in the ecosystem. In such situation, the improvement of water quality alone wouldn't be able to restore the ecosystem to its original state because the key players are no longer present. We call this "oligotrophication."

Abe•If that is the case, could we just put N and P in the Seto Inland Sea, just like we apply N chemical fertilizers to farmland?

Hayashi•We cannot undo the changes immediately. It would be difficult unless we return the key species that were there originally.

Abe•In Lake Biwa, several RIHN projects were doing work. Prof. Noboru Okuda's e-rec Project (*7) strongly focused on involving the local communities in the watershed, which led to the successful establishment of human network. This is what we can call an asset of RIHN, and I think you can leverage this for your project as well.

We can't resolve the issue unless we see the entire picture

Abe•When I first heard your project concept at one of RIHN's meetings, I thought, "they're going to do everything!"

Hayashi•Yes, we're doing (laughs).

Abe•After talking with you today, I do understand why.

Hayashi•It would be pointless when you control something and end up having something else overflow.

Abe•You think you are solving a problem, but it's like playing whack-a-mole.

Hayashi•If you know that "if you whack here, that will pop out," you would probably try pushing both a little.

Abe•The easiest way to get results is to simplify the problem. It would be easier to see the cause and effect in a linear relationship. This may be just fine in respective fields, but it will not resolve environmental issues. Interdisciplinarity is required.

Hayashi•Agree. The integration of natural, social, and cultural sciences is important here.

Abe•We do have to look at the full picture of the N issue, which is complex and intertwined. But at the same time, don't we also have to think about some sort of one-point breakthrough solution?

Hayashi•Thank you for your important question. I don't expect this project to address everything optimistically, but at least I want to make sure that people would know that there was/is this project at RIHN with a clear vision of "we can't resolve the issue unless we see the entire picture." Then there will be the hope that the next generation of those with determination will develop it further in the future. So, I want to be "a stone to be stepped

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*7 The RIHN Research Project "Biodiversity-driven Nutrient Cycling and Human Well-being in Social-Ecological Systems" completed in FY2019.

Nitrogen is "everywhere" and we cannot see why it's important

over" (laughs).

Abe●That's too soon to say things like that! Your project has only just started (laughs).

Hayashi●I think I will still be active for the time being, but that's what I am thinking about.

One of the important perspectives in environmental issues is when we take some action, reactions will accompany. As you pointed out, most of the measures taken for environmental issues to date have been a one-point breakthrough solution. As a result, it caused new problems in other areas. Therefore, what I would like to emphasize here is that it's necessary to have people with a broader vision.

Particularly, N is associated with almost all environmental issues, so if there is someone with such a broad vision, for example, he or she can say to those who try to resolve environmental issues with a one-point breakthrough approach, "you have to be careful because if you do that, you may encounter other problems like this."

Envisioning future with the Future Design

Hayashi●An advantage of this project is great international connections that we have. I've been a project member of the UN Environment Programme's (UNEP) program called International Nitrogen Management System (INMS) (*8). The UNEP holds the UN Environment Assembly (UNEA) every two years, where they will adopt the "Resolution on Sustainable Nitrogen Management."

However, the 5th UNEA in 2022 decided to focus on the topic of microplastics in the ocean, and consequently came up with very important actions to take. The issue of N management will probably be carried over to the next assembly in 2024. We're currently discussing creating a framework for how each member nation can address the international N management.

In response to this, I have proposed if our project could collaborate, for example, in communication such as the Future Design approach. Of course, we hope to commit our project to this international framework scientifically, but we would also like to assist people in each member nation to envision our future.

Abe●Prof. Yoshinori Nakagawa is working on RIHN Future Design project (*9).

Hayashi●The Future Design approach starts with an assumption that, for example, we become imaginary future persons living and eating happily in 2050 and think that "we are now (2050) in this state because we made some actions in the past since 2020." What I find interesting is that different ideas would emerge when we envision 2050 from the current situation that we are in and when we generate ideas based on what we did in the past (i.e., the present), immersing ourselves in pretending to be living in 2050.

At the very least, if you look from both perspectives, you will not suffer a loss. If you look at the present from the future as imaginary future persons and come up with interesting ideas, it's a lucky win; if not, that's what it was supposed to be anyways...... By applying the Future Design approach, our project can contribute to bring new ideas to the table.

Abe●I see, I think that is indeed a sort of breakthrough, or perhaps a way out.

When you introduced your project at one of RIHN's meetings, you mentioned that you were also thinking of contributing to the international N management led by UNEP, but to be honest, I'm not sure what exactly UNEP wants to do.

Hayashi●Yes, that's right. I think they're still discussing that.

Abe●If you can propose to incorporate the research results of your project and the Future Design process into the discussion, and present what should be done and what is important for the future of N management, I do feel a sense of hope that it will have a quite great impact.

Hayashi●I also have high hopes. I think it's quite a challenge, though. Nitrogen experts already have a pretty good grasp of the issue, but in an organization as vast as UNEP, it is up to the representatives of each member nation to regard the issue as their own.

*8 Scientists from around the world join to examine the need for global N management and effective management processes and investigate how improving N use will expand benefits (completed in June 2023).

*9 The RIHN Research Project "Development and Pluralistic Coexistence of Sustainability Visions Through Future Design" started in FR2022 as Full Research.

Kentaro Hayashi (left)
He specializes in biogeochemistry, soil science, and atmospheric science, and has a wide range of interests in biology, ecology, history, geography, food culture, etc. In FY2016, he participated in the 58th Japanese Antarctic Research Expedition (JARE) Summer Party. His main research interests are nitrogen cycling and sustainable use of nitrogen. After working as a Senior Principal Scientist at the Institute for Agro-Environmental Sciences, National Agriculture and Food Research Organization (NARO), he joined RIHN as a joint cross-appointment project leader in 2022, and fully moved to RIHN in 2023.

Ken-ichi Abe
He is a Professor and Head of Communication Unit Strategic Planning and Management Department at RIHN. His expertise is environmental anthropology. He has been a member of RIHN since 2008.

Humanity living toward the future of good hope

Abe●When we look at a complex issue like N, it is important to recognize the facts, of course, but in the end, we must also ask about value propositions, i.e., the question on how the issue should be.

Hayashi●I believe that the facts and values are all linked. How should we live? Or I should probably say how we want to live.

When I say that we should return the N cycling to how it used to be, everyone responds with "why?" But the N cycling is directly linked to our own life. If we can achieve the state of "further wellbeing," the N issue would be resolved before we recognize it. In fact, I sometimes wonder if such a solution would be better.

Envisioning the far future is one unique ability of humanity, I would say. We can draw a happy future and live toward it. Of course, the opposite is also possible, which is what I find scary about humanity.

Abe●It was a great talk today. Thank you very much.

June 15 (Wed), 2022: At the RIHN Courtyard

This interview was conducted in Japanese.
(Translated by Yuko Kobayashi)